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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Questionnaire data were collected aboard Navy auxiliary ships and experimental task simulations were carried out to extend the human factors data base established by the FY 1980 Women Aboard Ships Program. Questionnaire results were generally consistent with the FY 1980 data. Females reported more difficulties than males using special clothing and gear and reaching needed items. This was especially true of the smaller females. Females also rated habitability spaces lower than males. High proportions of both females and males cited difficulty with the use of ship fittings such as ladders, watertight doors and escape scuttles.

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Results of experimental simulations of fire fighting with a CO_2 extinguisher and starting a P-250 water pump were consistent with the questionnaire data. Females took longer than males to put out class C fires using a CO_2 extinguisher. Additionally, females registered significantly lower foot-pounds of force while pulling on a P-250 starter cord than males, with light females exerting less pulling force than heavier females. Females also exhibited a different pulling strategy than males did. The experimental results revealed that 85 percent of the females and 5 percent of the males sampled would be incapable of starting the P-250 pump.

Overall results indicated that the lesser grip and upper torso strength and reach envelope of females compared to males, as well as the poor fit of special gear and clothing contributes significantly to human engineering related difficulties in shipboard tasks. Approaches recommended to alleviate these problems include compensatory operator training, as well as equipment and clothing redesign. The need for human engineering guidelines to aid Naval architects is apparent. The utilization of such guidelines will contribute to increased effectiveness for tasks performed in the shipboard environment for all crewmembers, irrespective of sex differences.

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NAVAL ARCHITECTURAL RESEARCH FOR WOMEN ABOARD SHIP

RL Pepper, Code 533
MD Phillips, ISC, Inc

September 1982

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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ADMINISTRATIVE INFORMATION

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OBJECTIVE

Identify the extent of problems faced by women serving aboard ships, brought about by their working in an environment sized for males.

RESULTS

The greatest problems have been identified in the areas of shipfittings and ship system equipment (damage control) which, when used by female and smaller male personnel, cause seriously degraded performance at critical periods. Factors which contribute to these difficulties include differences in grip strength, upper torso strength and reach envelope.

Results of experimental simulations of fire fighting with a CO^2 extinguisher and starting a P-250 water pump were consistent with the questionnaire data. Females took longer than males to put out class C fires using a CO^2 extinguisher. Additionally, females registered significantly lower foot-pounds of force while pulling on a P-250 starter cord than males, with light females exerting less pulling force than heavier females. Females also exhibited a different pulling strategy than males did. The experimental results revealed that 85 percent of the females and 5 percent of the males sampled would be incapable of starting the P-250 pump.

Overall results indicated that the lesser grip and upper torso strength and reach envelope of females compared to males, as well as the poor fit of special gear and clothing contributes significantly to human engineering related difficulties in shipboard tasks. Approaches recommended to alleviate these problems include compensatory operator training, as well as equipment and clothing redesign. The need for human engineering guidelines to aid naval architects is apparent. The utilization of such guidelines will contribute to increased effectiveness for tasks performed in the shipboard environment for all crewmembers, irrespective of sex differences.

RECOMMENDATIONS

1. Develop a more substantial qualitative data base through continuation of the problem identification effort.
2. Develop a training plan to prepare female sailors for the proper methods for lifting, handling and carrying of heavy materials.
3. Prepare a data base management system for the storage and retrieval of male-female anthropometric, biomechanical and ergonomic difference literature.
4. Develop a set of human engineering guidelines for naval architects that includes male-female differences with respect to size and motion sensitivity.
5. Expand the literature search to include an evaluation of cognitive differences in female performance which impact Navy performance.
6. Conduct an analysis of the significance of the above differences with respect to potential C_3 applications and design an experimental paradigm to evaluate the utility of the differences in a relevant shipboard C^3 mission.

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INTRODUCTION

In the spring of 1980, NOSC was tasked by NAVSEA to determine the nature and extent of problems women may have as a result of working onboard ships which were designed to male size and strength dimensions. The initial emphasis was directed toward issues of personnel safety and survivability. The problem identification phase of this initial effort relied upon questionnaires, interviews, and observational techniques to identify and describe shipboard human engineering problems due to the anthropometric and biomechanical differences of the sexes (ref 1). An additional literature review concerning male-female difference with respect to anthropometry is reported elsewhere (ref 2).

The previous work revealed that females currently serving onboard ships lack experience using many ship fittings, equipment, and protective clothing. Seldom selected to handle some of the more physically-demanding jobs, the resulting lack of exposure of women to many ship system elements probably reduced the level of complaints. Additionally, the high motivational level of the female sailors has probably masked some equipment problems in the self-report indices employed.

Even with the above limitations of the data, several items of ship equipment, fittings and clothing emerged as being deficient for use by females. Protective gear such as the oxygen breathing apparatus (OBA), safety harness, life preserver and foul weather gear does not adequately fit many of the women on board. Hand tools and fire fighting equipment were found to be difficult for many of the women to operate. Ship fittings such as escape scuttles and water tight doors were also reported to present problems. These results are described in greater detail elsewhere (ref 1).

OBJECTIVES

The objective of the present report is to describe the results obtained to date from the Women Aboard Ship program. Thus, additional questionnaire data have been collected for analysis. The methods utilized and results obtained for the 1981 questionnaire administrations are described in later sections of this report.

In an effort to objectively verify problem areas identified in the qualitative data, an empirical investigation of female and male performance in selected shipboard tasks was designed. This experimental approach may circumvent some of the biases inherent in the qualitative data due to differences in experience and motivation found between the sexes. Additionally, an experimental analysis can bridge the potential gap between perceived and actual human engineering related difficulties. Later sections of this report describe the methods and results of the experiments conducted during FY 1981 for the Women Aboard Ship program.

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1. NOSC TR 658, Naval Architectural Research for Women Aboard Ship, by RL Pepper and MD Phillips, Unclassified, March 1981.

2. NOSC CR 107, Female and Male Size, Strength and Performance: A Review of Current Literature, by MD Phillips, A Bogardt and RL Pepper, Unclassified, November 1981.

QUESTIONNAIRE METHOD

Questionnaire data were obtained from a subset of personnel from the USS Point Loma (AGDS-2) and the USS Vulcan (AR-5). A total of 132 males and 93 females responded to the questionnaire administered aboard these two ships.

The questionnaire utilized aboard the Point Loma was attached to a "Women in the Navy" survey given by the Navy Personnel Research and Development Center (NPRDC). The human engineering attachment is shown in appendix A. The Vulcan questionnaire differed somewhat in format and was administered as shown in appendix B. Due to the different formats of these two questionnaires, separate analyses were performed on these data.

QUESTIONNAIRE RESULTS AND DISCUSSION

USS POINT LOMA SURVEY

The sample of respondents from the Point Loma consisted of 95 males and 44 females. The height and weight distributions of this sample correspond well with other samples of military personnel (ref 3, 4).

To get a clearer picture of how different size groups of males and females respond to these questions, the sample was broken up into three weight categories. The weight categories shown in table 1 were chosen to approximate a normalized distribution around the mean male and female weight values for this sample.

Male Categories

Group		Weight		(Lbs)	N
1	=	110	–	147	28
2	=	148	–	175	41
3	=	176	–	220	26

Female Categories

Group		Weight		(Lbs)	N
1	=	102	–	123	17
2	=	124	–	137	16
3	=	138	–	163	11

Table 1. USS Point Loma survey weight categories.

3. Natick Research and Development Command TR-77-024, Anthropometry of Women of the US Army, Report No 2, Basic Univariate Statistics, by E Churchill, T Churchill, JT McConville and RM White, Unclassified, 1977.

4. Natick Research and Development Command TR-77-029, Anthropometry of Women of the US Army, Report No 5, Comparative Data for US Army Men, by JT McConville, E Churchill, T Churchill and R White, Unclassified, 1977.

The percentages of respondents reporting problems with the fit of special clothing and gear are shown in table 2.

A chi data square test for differences in probabilities (ref 5) on frequencies of reports of good fit vs poor fit by sex (compiled across items listed) revealed that the overall differences are statistically significant, $X^2(2)$, = 30.50, $p<.01$.

Items that showed the largest differences between the sexes and the highest percentage of female "poor fit" ratings included foul weather gear, OBA and fire fighting suits. It should be noted that all of these items are commonly used in damage control and fire fighting operations.

This breakdown revealed that the highest incidences of "poor fit" ratings came from the group 1 and 2 females. Group 1 females reported the greatest incidence of poor fit weather gear (50%), OBA (40%) and fire fighting suits (20%). No problems (0%) were reported regarding life preservers or safety harnesses. It should be noted, though, that both these items had high "no experience" ratings by the group 1 females: 88% and -78% respectively.

Female reports of problems "usually" or "sometimes" were greater than male reports in all items listed. The reverse was true of respondents reporting that they never had problems (see table 3). A chi square analysis of responses category (summed across items) by sex indicated that the differences reported between the sexes with problems with ship fittings were significant, $X^2(2) = 19.40$, $p >.01$.

GROUP	Male Fit Rating (%)	Female Fit Rating (%)
1	4.0	20.6
2	5.1	16.5
3	3.12	2.9

Table 2. USS Point Loma survey special clothing and gear fit problems.

	USUALLY/SOMETIMES		ONLY AT SEA		NEVER	
	MALE (%)	FEMALE (%)	MALE (%)	FEMALE (%)	MALE (%)	FEMALE (%)
Ladders	16	38	8	24	76	38
Water Tight Doors	16	26	9	8	75	66
Escape Scuttles	20	37	5	11	75	52

Table 3. USS Point Loma survey problem reporting.

5. Conover, WJ, Practical Nonparametric Statistics, John Wiley and Sons, Inc, New York, 1977.

The higher incidence of females reporting difficulty using ship fittings (ladders, water tight doors, escape scuttles) at sea may either be a result of differential human engineering problems due to different anthropometric accommodation, or differences in adaptation due to differences in time at sea.

At this time in the Women Aboard Ship program, males still have had much more sea experience than females. It is possible that increased exposure to ship fitting use under conditions of ship motion facilitates an adaptive process whereby the crew member learns more efficient coping strategies. It is conversely possible that increased exposure will increase the frequency and variety of human engineering problems for the smaller female complement. This question of anthropometric accommodation vs adaptation will be more fully understood as females gain more experience at sea.

Examining the data compiled by the weight groups described earlier, the greatest difficulties with ship fitting use were again registered by group 1 females. Here, problems were reported "usually" or "sometimes" by 40% of the group 1 females for ladders, 30% for water tight doors, and 40% for escape scuttles. These figures correspond to group 1 male entries of 12%, 16% and 20% respectively.

Other questions in the Point Loma survey concerning the working environment also revealed that the greatest problems were incurred by the smallest (group 1) female personnel. The highest percentage reporting trouble reaching equipment, accessories and fittings was predictably the group 1 females (44%). Group 1 females also reported the most tripping and bumping problems (80%).

Negligible differences across groups and sexes were found in questions about interference with work due to ship motion. Here, 28% of the males and 29% of the females reported motion related difficulties. Fewer females (12%) than males (20%) indicated that jobs were difficult due to lack of time given for their completion. This suggests either that females are more efficient workers than males or that they are less inclined to report complaints concerning their job schedule.

Questions regarding motion sickness by and large yielded similar results for both sexes. Four percent of the males and 7% of the females experienced motion sickness often. Twenty-nine percent of the males and 24% of the females experienced motion sickness sometimes. More females (40%) than males (24%), however, reported to sick call as a result of motion sickness. Females also tended to feel more uncomfortable (20%) than males (10%) about reporting to sick call as a result of motion sickness.

USS VULCAN SURVEY

The USS Vulcan (AR-5) sample included 49 females and 37 males. A comparison of the physical dimensions with those reported from the Point Loma sample indicate that these two samples were anthropometrically similar.

The deployment experience of males and females of the USS Vulcan indicates that males had far greater experience at sea. The male sample averaged over 4.8 years at sea compared to the female average of only 1.5 years of sea duty.

The questionnaire utilized on the USS Vulcan allowed the respondent to rate items of special gear and clothing on a five point scale which ranged from "very poor" (1) to "very good" (5). If the respondent had no experience with the item in question, a response of "no experience" (6) was given.

For the purposes of this analysis, this five point rating scale was assumed to reflect interval level measurements; intervals between scores are therefore viewed as equivalent between any two adjacent points on the scale. This assumption allows the use of parametric techniques to interpret the data. The use of parametric techniques is preferred due to the greater statistical power made available than that of nonparametric methods. While interval level assumptions of questionnaire responses are subject to debate, parametric methods are generally robust to reasonable fluctuations from "ideal" population and measurement assumptions.

An analysis of the results of the "special clothing gear" section of this questionnaire showed that female mean ratings were significantly lower than male ratings on all items listed.

A greater percentage of females than males reported having no experience with the listed items, although the disparity of experience between the genders appeared to be less than that cited in earlier work (ref 1). Responses of "no experience" using the items listed are shown in table 4.

Respondents who rated an item of special clothing and gear as very poor (1) or poor (2) were asked if their rating were a result of inadequate fit, weight, body movement restrictions or other causes. Overall, female complaints of poor fit were slightly higher than that of males (female = 48%, male = 38%). Conversely, male complaints of body movement restrictions were higher than females (female = 27%, male = 36%). Similar proportions of females and males overall reported problems concerning weight (approximately 15%) and other causes (approximately 13%).

Higher proportions of poor fit ratings were given by both males and females to foul weather gear. More females than males reported poor fit with safety harnesses, fire fighting suits, life preservers, and the MK-V mask. The weight of the OBA was noted as a problem by both males and females. The highest incidence of female body movement problems concerned the safety harness, while male complaints centered on the OBA and fire fighting suit. More males (68%) than females (42%) stated that foul weather gear caused overheating during periods of exertion. A greater proportion of males (39%) than females (20%) registered the same complaint about fire fighting suits.

As in the Point Loma analysis, this sample of respondents was broken down by weight group, as shown in table 5.

Item	Female (%)	Male (%)
Safety harness	69	43
Foul weather gear	16	11
OBA	18	0
Fire fighting suit	68	57
Life preserver	36	24
Airline mask	90	76
MK-V mask	37	19

Table 4. USS Vulcan survey "no experience" responses.

	MALE CATEGORIES	
GROUP	WEIGHT (LBS)	N
1	130 – 150	12
2	159 – 181	15
3	182 – 234	10
	FEMALE CATEGORIES	
GROUP	WEIGHT (LBS)	N
1	95 – 124	16
2	125 – 136	19
3	137 – 160	14

Table 5. USS Vulcan survey weight categories.

Breaking the data down in this manner revealed that the worst overall ratings of special clothing and gear came from the group 1 (smallest) males and females. The mean special clothing and gear ratings per group are shown in table 6.

Approximately 85% of both females and males found it difficult to carry stores up or down ship's stairs. More females (35%) than males (25%) attributed the cause of the difficulty to the size or weight of the stores. About one-third of the males and females attributed the difficulty to ladders being too steep.

Many females (78%) and males (73%) complained of tripping or bumping on open stairwells. Escape scuttles were found difficult to use by 48% of the females and 68% of the males. The reasons given for difficulty with scuttle use are listed in table 7.

Female difficulties with scuttle use centered on both the inadequacy of the support areas and pushing from below. This is consistent with the lesser biomechanical advantage that shorter females would have when reaching the scuttle from the ladder below. Generating force above the shoulder level to push the scuttle up is also expected to be difficult for females due to their proportionally and absolutely less upper torso muscle mass compared to males (ref 6).

A recent survey of force required to open scuttles (ref 7) revealed that push forces needed to open scuttles can range from 42-65 pounds, depending on scuttle size and stage of

6. Pacific Missile Test Center Report, Classification, Summary, Relevance and Application of Male/Female Differences in Performance, by MM Ayoub et al, prepared under contract number N36126-77-M-4098, Unclassified, 1978.

7. Navy Personnel Research and Development Center, Occupational Physical Standards Project: Data Bank, by DW Robertson and T Trent, Unclassified, 1980.

GROUP	FEMALE RATING	MALE RATING
1	2.80	3.72
2	3.04	3.74
3	3.22	3.20

Table 6. Special clothing and gear ratings.

	Female (%)	Male (%)
Hard to fit through	0	16
Hard to push up from below	33	23
Hard to pull up from above	18	7
Hard to turn wheel	11	26
Lack of support areas (handholds, footholds)	38	28

Table 7. USS Vulcan survey scuttle problem data.

lift. (Force needed varies as the angle between the scuttle and the deck changes from 0° to 90°). This range of force falls between the 35th and 75th percentile of female two handed, shoulder height, upward push capability (ref 3). Note that only one hand is available to push a scuttle up from below decks because the other is needed to grasp the ladder.

Males also reported difficulties with lack of support areas and pushing the scuttle up from below. More males than females noted that turning the locking wheel was difficult. About one third of the group 3 males cited "hard to fit through" as a problem with scuttle use.

Half of both female and male respondents noted that water tight doors were hard to use. The highest response on this question was given by the group 1 females (71%). The most common problem cited was difficulty unlocking dogs. The Robertson and Trent survey (ref 7) indicated that force requirements to open water tight door latches varied greatly as a function of door type (quick acting, individually dogged, etc.), state of repair, and stage of pull. An example of an eight dog door listed in their survey showed forces to open four of the dogs ranging from 28 to 58 pounds of force. The other four dogs on this door were disfunctional. Pulling forces measured at three stages on one quick acting (single lever) door ranged from 42 to 85 pounds. Another quick acting door measured in the same manner showed force values ranging from 37 to 112 pounds.

Due to the great variety in heights, angles of access and handle configurations of water tight doors, it is impossible to select a force value indicative of female or male capabilities with respect to these force requirements. The range of values noted by Robertson and Trent in reference 7, however, is consistent with the high incidence of reports by females and males concerned with the difficulty of unlocking water tight doors.

In an open response question identifying tools and supplies reported as difficult to use due to grip configurations, size/shape or weight, females listed many more items than males. No inferences can be drawn from response rates, though, because rate of response could be affected by a tendency to answer free response questions, greater difficulties with tool use, or other factors.

Forty-seven percent of females and males indicated that ship motion interfered with their work. Many tasks were listed by respondents as more difficult to perform due to ship motion.

More women (33%) than men (25%) reported difficulties reaching needed controls, equipment or accessories. Here again, the greatest reach difficulties were reported by the group 1 females. Reach difficulties involving making up the rack or accessing rack stowage were also reported by more women (53%) than men (33%).

Questions concerning berthing areas employed the five point rating scale. Overall, females tended to rate their berthing areas significantly lower than males did, $t(420) = 2.70$, $p < .01$. Low ratings were given by both females and males on ventilation. Females rated privacy and amount of storage space lower than males.

Females reported slightly more problems with motion sickness than males did. Fourteen percent of the females experienced motion sickness of any kind "always" or "fairly often", while only eight percent of males did. Twenty-two percent of the females reported that motion sickness occurred during a deployment "always" or "fairly often", compared to eight percent of the male crew.

Consistent with these reports was the slightly greater proportion of females (41%) than males (32%) who, after becoming seasick, needed to report to sick call.

Males (31%) had a greater tendency to report that seeing other people seasick caused them to become seasick than females (23%). On the other hand, more females (62%) than males (45%) indicated that smelling strong odors caused seasickness.

EXPERIMENTAL METHOD

The experimental phase of the FY 1981 program was carried out at the Fire Fighting (FF) school located at the US Navy Fleet Training Center in San Diego. Fire Fighting school provided an opportunity to examine critical, real world shipboard tasks in a somewhat controlled environment. At FF school, the same equipment, tools and protective gear issued to fight fires on board ship were used in these simulations.

Fire fighting tasks were chosen for evaluation for the following reasons:

1. All personnel may need to perform as fire fighters.
2. Successful task performance is highly critical in emergency conditions.
3. Special clothing and gear (reported as problematical by females in ref 1) are used in some fire fighting tasks.
4. Some fire fighting equipment was reported to be inadequate for female use in reference 1.

EXPERIMENTAL TASKS

Two tasks were chosen for evaluation at FF school. These were fighting a class C (electrical) fire with a standard Navy CO_2 portable extinguisher, and starting a P-250 pump. The critical elements involved in the CO_2 task were dynamic upper torso strength, grip strength, and special clothing and gear use. The P-250 task involved primarily explosive upper torso strength and grip strength.

CO_2 TASK

Subjects

Subjects were 16 male and 16 female enlisted Navy personnel recruited from the USS McKee (AS-41). The female sample ranged from the 5th to the 70th percentile of military females in weight (ref 3). This range was 105 lb to 140 lb, with a mean weight of 119.63 lb. The male sample ranged from the 10th to the 95th percentile in weight (ref 4). This range was 130 lb to 202 lb, with a mean weight of 169.13 lb. No measures of relative experience with fire fighting equipment were taken. The experiment was incorporated into an extensive fire fighting and damage control training program in which all of the subjects were required to participate.

Procedure

Subjects were randomly assigned to one of 32 positions in a lineup inside a bunker which simulated a lower port side ship compartment. As subjects came to the front of the line, they were required to observe and verbally report a simulated class C fire. The fire was actually fueled by one quart of diesel fuel spilled over an electric motor frame. After the subject made the report, he or she carried a 50-lb CO_2 extinguisher a short distance (7 - 8 feet) and fought the blaze. All subjects wore foul weather gear, including boots and gloves, for this task, as shown in fig 1.

A time measure was taken with a stopwatch from the time the CO_2 extinguisher was activated until the fire was reported to be out. As each subject completed the task, they reported their weight to the experimenter. The experimenter then recorded this weight, the time required to extinguish the fire, and noted whether the subject was a male or a female.

P-250 TASK

Subjects

Subjects were 20 male and 20 female personnel. This sample of females ranged from the 5th to 90th percentile of military females in weight (105 lb to 155 lb) with a mean weight of 121.85 lb. The male sample ranged from the 15th to 95th percentile (135 lb to 202 lb) with a mean weight of 168.25 lb. (Females and male percentile ranks were derived from references 3 and 4. As in the prior task, all subjects were required to participate in the study as part of a training program. Most of the P-250 subjects also participated in the CO_2 task.

Procedure

The P-250 task involved pulling a starting cord on a P-250 water pump. The P-250 is a portable, gasoline powered pump used for dewatering flooded compartments and fire fighting. The pump is contained in a steel frame which measures 30" X 36" X 36". Without the gas tank, the pump weighs 147 pounds. It is started by pulling a cord which is similar to a starting cord found on an outboard engine. The fuel line was detached from the pump engine so as to prevent ignition during the experiment. Standard Navy issue work clothes were worn during this task. Figure 2 illustrates both the P-250 pump and the manner in which most female subjects attempted to start the pump.

A Dillon load cell wired to a Dillon force transducer was attached to the starter cord of the pump. Figure 3 shows a picture of the meter and the load cell. This apparatus permitted a direct reading of the foot-pounds of force exerted on the starter cord.

Subjects were chosen in random order. They were directed to pull on the starter cord in a sincere attempt to start the pump. Subjects were instructed to use any stance or grip that felt comfortable to them. All subjects were allowed three attempts; the best of the three tries was recorded. After completion of the task, each subject reported his or her weight to the experimenter. The experimenter recorded the force level achieved, the subject's weight, and noted the subject's sex.

EXPERIMENT RESULTS AND DISCUSSION

CO_2 TASK

In order to view the effects of size as well as sex on fire fighting performance, males and females were grouped into two weight categories. While grouping and matching according to percentile ranks was desired, limited subject availability only allowed grouping according to a median split along the obtained weight distribution. While grouping in this manner is somewhat arbitrary, it does provide a limited means of investigating the very important size variable in these tasks within the real-world constraints of this study. The female sample was split at the the median value of 120 lb; the male sample was split at 165 lb. The female sample ranged from the 5th to the 70th percentile of military females in weight, while the male sample ranged from the 10th to the 95th percentile in weight (ref 4).

Females required more time to extinguish the fire than did males, and smaller females took longer than larger females (table 8).

A 2 X 2 (sex X weight) Analysis of Variance (ANOVA) (ref 8) performed on these data showed that the main effect of sex difference of weight group and the interaction of weight group by sex were not significant. ($F(1,28) = 3.85$ $p < .10$)

While size matching was not possible in this study (as noted earlier), there was some degree of overlap in the obtained weight distributions of females and males. In examining the performance of the subjects, it is obvious that weight matched females also took longer than their male counterparts to extinguish the fires.

It should be noted that many females were observed to have great difficulty carrying the extinguisher out of the bunker (especially lifting it over a 12" bottom door lip) after the

8. Winer, BJ, Statistical Principles in Experimental Design, 2d ed, McGraw-Hill, New York, 1971.

Figure 1. Female subject carrying CO_2 fire extinguisher.

Figure 2. Female subject attempting to start P-250 pump.

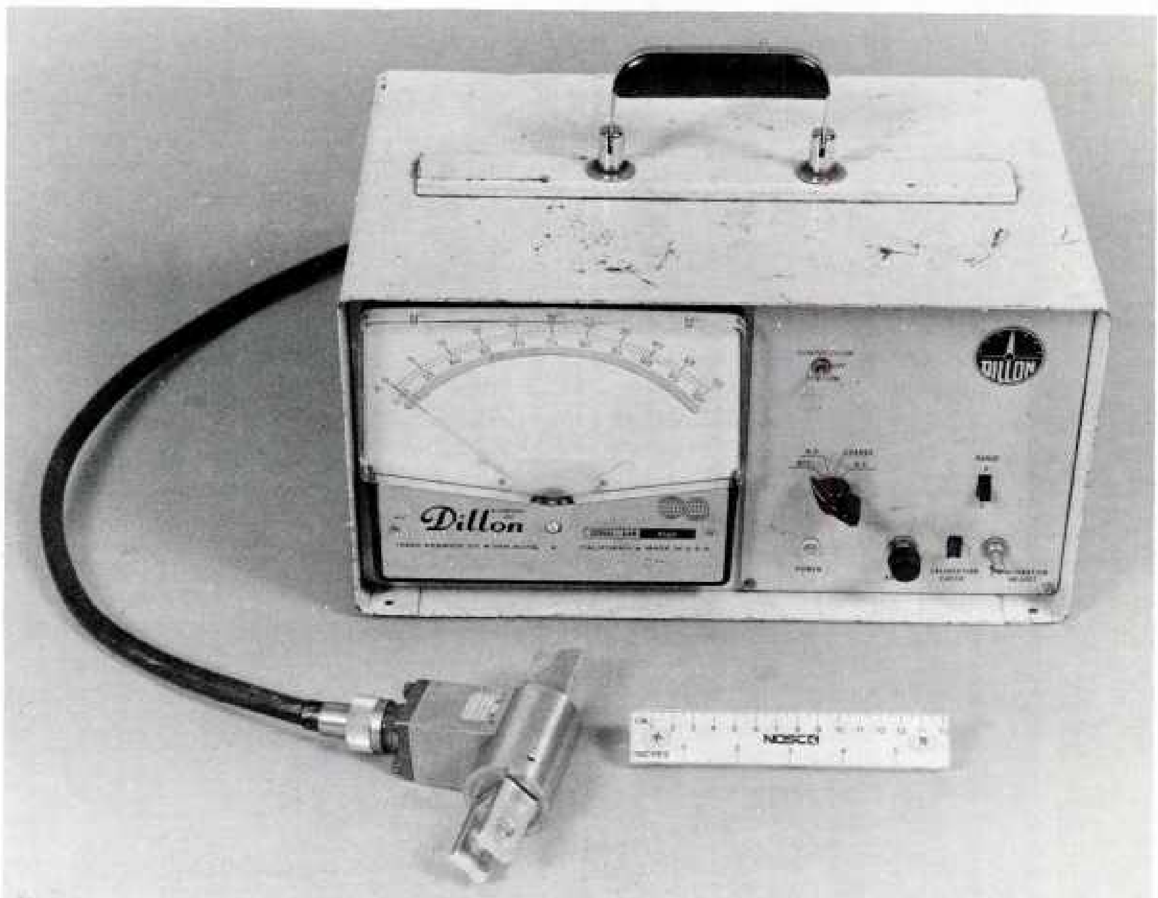

Figure 3. Dillon load cell and readout.

	Group 1		Group 2	
	x*	SD	x	SD
Female	18.13	6.81	14.50	2.39
Male	13.00	5.04	12.25	5.70

*Time in seconds.

$p < .01$ is statistically significant as stated.

Table 8. Time required to extinguish fires.

fire fighting task was completed. This difficulty was not apparent in the male subjects. Due to constraints imposed by the schedule of the overall training program, it was not possible to add a lifting and distance carrying component to the fire fighting task. If this additional component were added, the results obtained for the CO_2 task may have revealed much greater sex-based differences than those reported here.

When viewing the obtained differences, practical significance should be examined as well as statistical significance. The difference in means between group 1 females and group 2 males is almost 6 seconds, or approximately 50% longer to extinguish the fire. This difference does not include lifting and carrying the extinguisher to the site of the blaze; it is solely additional fire fighting time.

While fire fighting experts are in the best position to judge whether these time differences are cause for concern, it must be noted that in an emergency condition, a small female might indeed be required to locate a CO_2 extinguisher, carry it to the blaze and commence fighting the fire. The result of this evaluation suggests that one could expect more time for the fire to spread in such a case. CO_2 extinguishers with more biomechanically advantageous grip areas and perhaps shoulder straps may alleviate this problem. The possible use of lighter materials for container construction should also be considered.

P-250 TASK

A median split, as described previously, was used to group the P-250 task sample. The female and male samples were again split at their respective median values of 120 lb and 165 lb for the small and large dichotomy.

Females registered lower foot-pounds of force than males on this task, with group 1 females registering lower readings than group 2 females. The mean foot-pounds of force registered are shown in table 9.

To put these means in perspective, baseline measures on this task indicated that a well maintained P-250 requires 16 – 20 ft-lb of force to start the pump. The values obtained indicate that 85% of the women and 5% of the men sampled would not be able to start the P-250, even under optimal conditions.

A 2 X 2 ANOVA conducted on these data indicate that the effect of sex of subject on task performance was significant: $F(1,36) = 68.65$, $p<.001$. The effect of sex accounted for almost two-thirds of the variance in this data set. The sex by weight group interaction was also significant: $F(1,36) = 5.34$, $p<.05$.

	Group 1		Group 2	
	x	SD	x	SD
Females	10.40	3.20	14.10	3.14
Males	19.80	1.87	19.40	2.80

Table 9. Mean foot-pounds of force registered in attempting to start P-250 pump.

The results support the expected outcome that males could exert more foot-pounds of starting force than females. Additionally, while weight group makes no difference in force exerted on the P-250 by males, it does impact the performance of females. Further evidence of this effect is revealed by examining the correlations between weight and performance in the male and female samples. The Pearson product-moment correlation obtained for the female sample showed a significant positive correlation between subject's weight and foot-pounds exerted: $r = .51, p < .05$. The correlation obtained for the male sailors did not approach significance: $r = .01$. See figure 4 for a graphic description of the regression of weight against performance.

The sex by weight group interaction may result in part from the different strategies males and females employed during the P-250 task. Males tended to exert a single explosive motion, while females applied a more continuous pull on the cord. The larger overall mass of the group 2 females compared to the group 1 females may in some degree compensate for the lower upper torso strength females have than males (ref 9). The greater mass can thus be converted into increased foot-pounds of force when using the continuous force application technique typical of females. The greater male upper torso strength, exhibited by use of the explosive motion, may have negated the effects of weight group (mass) on male performance.

The performance of the weight matched subset of subjects was consistent with the main effect of sex in the overall results. Thus, females exerted less foot-pounds of force than did the weight matched males, as shown in table 10 below.

At least two approaches are available to rectify the human engineering problems identified with P-250 pump use. The first is compensatory operator training, and the second is in hardware redesign. It may be that the less efficient pulling strategy exhibited by females is primarily a result of inexperience in physical tasks of this nature. If this is the case, training in correct pulling techniques may go a long way towards alleviating the starting problem. If compensatory training fails to bring performance up to criteria, equipment redesign needs to be considered.

Pepper and Phillips (ref 1) found the P-250 to be difficult to start and difficult to lift and carry for smaller sailors. Redesign efforts for the P-250 should therefore focus on starting and portability. An ideal solution to the starting problem would be to replace the

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9. Aerospace Medical Research Laboratory AMRL-TR-75-32, Muscular Strength of Women and Men: A Comparative Study, by LL Laubach, Unclassified, 1976.

Female		Male	
Weight	Foot-Pounds	Weight	Foot-Pounds
138	9	135	19
140	17	140	18
145	12	145	23
155	14	155	20

Table 10. Foot-pounds of force exerted by weight-matched female and male subjects.

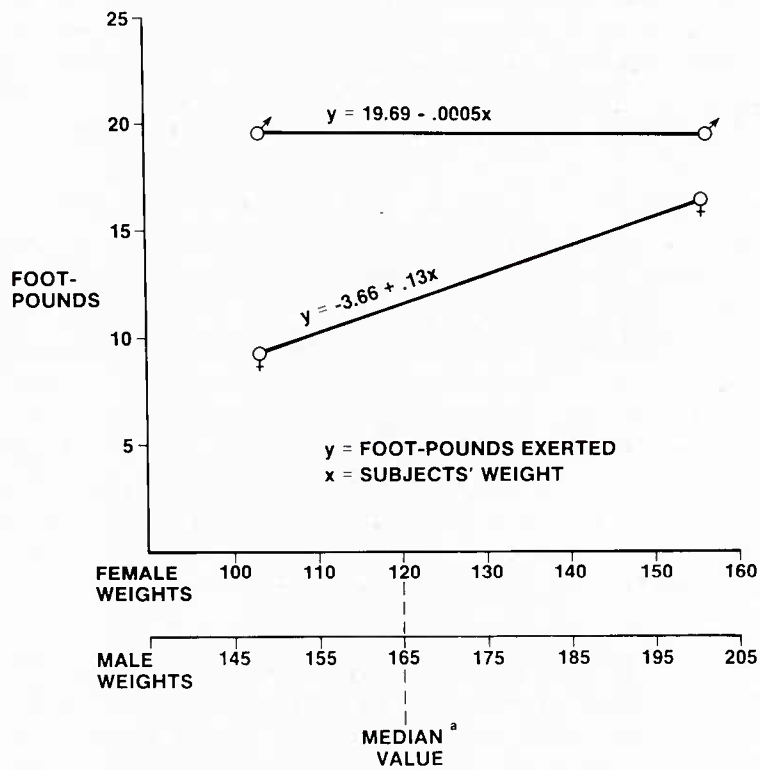

Figure 4. Regression of female and male subjects' weight on foot-pounds of force exerted on the P-250 task.

pull cord with an electric starter and solid state electronic ignition. If this is deemed impractical, different handle configurations and pull cord locations should be evaluated, perhaps employing a spring wound starter mechanism.

Portability could be facilitated by building the pump in smaller, modular units. A less costly modification would be to redesign the carrying frame and grip surface and to add locking wheels to aid moving the pump along long flat decks. Similar alternatives should be considered for all shipboard equipment that requires grip activation and significant upper torso strength.

CONCLUSION

Combining experimental techniques with qualitative problem descriptive efforts enabled a more complete and accurate analysis than a study which focused solely on one or the other method. The empirical investigation reported here adds substantive support to the results of the descriptive study. For example, females (especially group 1 females) registered lower foot-pounds of force in starting the P-250 pump and exhibited a different pulling strategy than males did. This finding specifically supported FY 1980 questionnaire reports of female difficulty in starting the P-250. These findings also lend support to FY 1981 reports of female difficulty with similar tasks involving a combination of upper torso strength and grip strength (e.g., operating the sand blaster or deck grinder).

The questionnaire data reported here were generally consistent with the data derived in FY 1980. The major factors associated with female human engineering problems identified in FY 1980 involved special clothing and gear use, upper torso and grip strength and reach envelope. These factors emerged again in the FY 1981 data. Also apparent in these two qualitative data sets is that the population least accommodated by current clothing, equipment and ship fitting configurations is the group 1 (small) females. Here again, qualitative reports of difficulties by this sub-set of subjects were supported by the experimental results.

Some potential solutions to the problems identified with the P-250 pump and the CO_2 extinguisher were discussed earlier (see Experimental Results and Discussion). It is likely that the design of other items of shipboard equipment would benefit from a similar methodological approach.

The empirical methods used here allowed a systematic identification of equipment problems that would not be possible using paper and pencil methods which attempt to match human performance data with equipment use requirements (ref 10, 11). For example, females used a different pulling strategy than males during the evaluation. This may have training as well as design implications which would not be apparent from data which simply show male/female force production capabilities. It should also be noted that biomechanical data (ref 9) are task and position specific. In other words, the values obtained often will not generalize to real world conditions where operators have limits on their body position, grip surface, etc.

Equipment redesign practicality and cost can be viewed in terms of overall system needs. Retrofit options for already existing equipment may indeed be limited, although some "quick fixes" can be found to be both practical and effective (for example, adding locking wheels to the P-250 frame). When considering retrofit costs, the consequences (and cost) of operator failure to perform due to difficult-to-use equipment must be judged. The difficulty of small females in moving the CO_2 extinguisher is a good example of a potentially critical operator failure.

Finally, new equipment, still in the development stages, should be designed for use by the full complement of female and male crew. Design guidelines need to be developed

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10. National Bureau of Standards Technical Report NBSIR-79-1949 (Navy), Evaluation of Selected Navy Equipment for the Women Aboard Ship Program, by RL Palla, Jr, CE Jones, CD Lovett and LG Porter, Unclassified, January 1980.

11. Advanced Marine Enterprises, Suitability of Hull and Damage Control Equipment and Systems for Women Aboard Ship, Arlington, VA, March 1980.

from data such as is presented here and in other sources to assist ship architects and designers in creating appropriately configured ship equipment and fittings. These "human engineered" designs should then be empirically assessed to assure that equipment use requirements conform to human capabilities.

REFERENCES

1. NOSC TR 658, Naval Architectural Research for Women Aboard Ship, RL Pepper and MD Phillips, Unclassified, March 1981.
2. NOSC CR 107, Female and Male Size, Strength and Performance: A Review of Current Literature, by MD Phillips, A Bogardt and RL Pepper, Unclassified, November 1981.
3. Natick Research and Development Command TR-77-024, Anthropometry of Women of the US Army, Report No 2, Basic Univariate Statistics, by E Churchill, T Churchill, JT McConville and RM White, Unclassified, 1977.
4. Natick Research and Development Command TR-77-029, Anthropometry of Women of the US Army, Report No 5, Comparative Data for US Army Men, by JT McConville, E Churchill and R White, Unclassified, 1977.
5. Conover, WJ, Practical Nonparametric Statistics, John Wiley and Sons, Inc, New York, 1971.
6. Pacific Missile Test Center Report, Classification, Summary, Relevance and Application of Male/Female Differences in Performance, by MM Ayoub et al, prepared under contract number N36126-77-M-4098, Unclassified, 1978.
7. Navy Personnel Research and Development Center, Occupational Physical Standards Project: Data Bank, by DW Robertson and T Trent, Unclassified, 1980.
8. Winer, BJ, Statistical Principles in Experimental Design, 2d ed, McGraw-Hill, New York, 1971.
9. Aerospace Medical Research Laboratory AMRL-TR-75-32, Muscular Strength of Women and Men: A Comparative Study, by LL Laubach, Unclassified, 1976.
10. National Bureau of Standards Technical Report NBS1R-79-1949 (Navy), Evaluation of Selected Navy Equipment for the Women Aboard Ship Program, by RL Palla, Jr, CE Jones, CD Lovett and LG Porter, Unclassified, January 1980.
11. Advanced Marine Enterprises, Suitability of Hull and Damage Control Equipment and Systems for Women Aboard Ship, Arlington, VA, March 1980.

APPENDIX A

USS POINT LOMA (AGDS-2) QUESTIONNAIRE

The questionnaire administered to personnel aboard USS Point Loma was included as part of a larger questionnaire. The questions pertaining to the study reported here began with question number 75, and are listed in this appendix.

75. Print your age:

76. What is your highest level of education?
    1. 8th grade or less
    2. Some high school
    3. High school graduate or GED
    4. Some college or Associate Degree
    5. College graduate (Bachelor's Degree)
    6. Some graduate work (Master's or Ph.D.)

77. How long have you been in the Navy?
    1. Less than one year (12 months or less)
    2. 1 to 2 years (13 to 24 months)
    3. 2 to 5 years (25 to 60 months)
    4. 5 to 10 years
    5. Over 10 years

78. If enlisted, which enlistment are you currently in?
    1. First
    2. Second
    3. Third
    4. Fourth or more

79. Did you volunteer for sea duty?
    1. Yes
    2. No

80. Were you assigned to a Damage Control Party?
    1. Yes (list job(s) assigned to)
    2. No

81. What is your height inches

82. What is your weight pounds

83. Using the scale below, rate how physically fit you are. Mark "X" on one of the lines between "Very fit" and "Very unfit".

    Very unfit Very fit

84. Using the scale below, rate how strong you consider yourself to be considering your size and sex.

    Very weak Very strong

Are you having problems with the fit of the following special gear or clothing? Please use the coding system below.

1 = Poor fit
2 = No problem
3 = No experience

85. Safety Harness

86. Foul Weather Gear

87. OBA

88. Fire Fighting Suit (Asbestos)

89. Life Preserver

90. Airline Mask

91. Is it more difficult for you to do your job when you are wearing any special gear or clothing?

YES NO

If you answered YES to #91, please list below the two jobs most affected by wearing special gear or clothing:

92.

93.

Is it ever difficult to use the following shipfittings? Use the coding system below.

1 = Usually
2 = Sometimes
3 = Only at sea
4 = Never

94. Ladders

95. Water Tight Doors

96. Escape Scuttles

Problems with the use of tools and equipment are usually caused by one or more of the following: poor size or shape, or because they are too heavy. For questions 97 to 101, please list the tools or equipment that you use that give you problems in any of these areas. Check the column that shows the type of problem(s) that may occur with their use. You may check more than one box for each question. If you have no problems with tools or equipment to report, leave this section blank.

97.

98.

99.

100.

101.

102. Does ship motion or foul weather interfere with your work?

YES NO

If you answered YES to #102, please list below the two jobs most affected by ship motion or foul weather.

103.

104.

105. Do you ever have trouble reaching any equipment, accessories, or ship fittings in work or living areas?

YES NO

If you answered YES to #105, please list below the two most difficult things for you to reach.

106.

107.

108. Are there objects in your workplace or living quarters that people trip over or bump into, especially in rough sea states?

YES NO

If you answered YES to #108, please list two of these objects.

109.

110.

111. Are there jobs that are difficult because you are given too little time to complete them?

YES NO

If you answered YES to #111, please list the two jobs that are most difficult due to the amount of time you are given to finish them.

112.

113.

114. How often do you experience motion sickness of any kind? (Example: carsick, etc.)

1 = Always
2 = Fairly often
3 = Sometimes
4 = Never

115. Has the ship been deployed for 2 or more days since you came aboard?

1 = Yes
2 = No

116. Have you experienced seasickness during a deployment?

1 = Yes, always
2 = Yes, fairly often
3 = Yes, sometimes
4 = No
5 = Never been deployed

117. On a scale of 1 to 5, with 1 being never seasick and 5 being extremely seasick, how seasick do you usually get?

Never seasick Extremely seasick

118. What type of remedy have you used for seasickness? (Medical or otherwise) (You may choose more than one response)

1 = Vomit
2 = Motion sickness pill
3 = Fresh air
4 = Nothing
5 = Other (please specify)

119. How well does your remedy work? (Leave blank if never been seasick)

1 = Very well
2 = Very well at first, but nausea returned
3 = Fairly well
4 = Fairly poorly
5 = Not at all

120. Have you reported to sick call due to seasickness?

1 = Yes
2 = Yes, but felt uncomfortable about doing so
3 = No, because I did not feel comfortable doing so
4 = No, I took care of it myself

121. Does seeing other people experiencing seasickness make you feel seasick?

1 = Yes
2 = No
3 = Don't know

122. Does smelling strong odors (diesel smoke, fuel vapors, cigar or cigarette smoke, cooking odors) make you feel seasick?

1 = Definitely yes
2 = Somewhat yes

3 = Somewhat no
4 = Definitely no
5 = Don't know

APPENDIX B
USS VULCAN (AR-5) QUESTIONNAIRE

Please fill in the following information:

1. Height
2. Weight
3. Sex
4. Sea duty years, months

Please rate the items of special gear and clothing listed below. When rating, consider if it is easy or difficult to work when wearing the item, as well as comfort. For each item listed, circle one number. If you have never used the item, circle #6.

5. Safety Harness
6. Foul Weather Gear
7. OBA
8. Fire Fighting Suit
9. Life Preserver
10. Airline Mask
11. MK-V Mask

For any of the items that you rated #1 or #2, please place a check under one or more of the reasons given below. If you rated #3, #4, #5, or #6, leave blank.

12. Safety Harness
13. Foul Weather Gear
14. OBA
15. Fire Fighting Suit
16. Life Preserver
17. Airline Mask
18. MK-V Mask
19. Does wearing foul weather gear cause you to overheat during moderate to heavy work?

    CHECK ONE: YES NO NO EXPERIENCE

20. Does wearing a fire fighting suit cause your body to overheat during moderate to heavy work?

    CHECK ONE: YES NO NO EXPERIENCE

21. Do you find it hard to carry stores up or down ships' stairs?

    YES NO

22. If you answered "YES" to #21, please check one or more of the reasons listed below:

Size or weight of stores

Hard to balance myself on ships' ladders

Ladders too steep

Footholds/handholds inadequate

23. Do you ever trip or bump yourself on open stairwells?

YES NO

24. Do you sometimes find escape scuttles hard to use?

YES NO

25. If you answered "YES" to #24, please check one or more of these reasons listed below:

Hard to fit through

Hard to push up from below

Hard to pull up from above

Hard to turn wheel

Not enough places to support myself (handholds, footholds, etc.)

26. Do you sometimes find water-tight doors hard to use?

YES NO

27. If you answered "YES" to #26, please check one or more of the reasons listed below:

Hard to unlock doors

Door too heavy

Tripping or bumping problem

For questions 28–30, please list the tools, equipment, or supplies that you feel are hard to use because of their grip, size/shape, or weight. First, list the item in the space provided, then check the column that corresponds to the type of problems that they have. You may check more than one box for each item you list. If you have no problem with tools, equipment, or supplies to report, leave this section blank.

28.

29.

30.

31. Does ship motion make it difficult to do your job?

YES NO

32. If you answered "YES" to #24, please list job and the tools or equipment used in that job that are the hardest to use because of ship motion.

JOB TOOLS OR EQUIPMENT USED IN JOB

33. Do you ever have trouble reaching any controls, equipment, or accessories that you need?

YES NO

34. If "YES", please list some hard-to-reach items below:

Please rate your berthing area on the following items (Circle One):

35. Ventilation

36. Lighting

37. Privacy

38. Security

39. Amount of Storage Space

40. Do you ever have trouble reaching and lifting your rack to get to the stowage compartment or to make it up?

YES NO

41. How often do you experience motion sickness of any kind? (Example: carsick, etc.)

1 = Always
2 = Fairly often
3 = Sometimes
4 = Never

42. Has the ship been deployed for 2 or more days since you came aboard?

1 = YES
2 = NO

43. Have you experienced seasicknesses during a deployment?

1 = Yes, always
2 = Yes, fairly often
3 = Yes, sometimes
4 = No
5 = Never been deployed

44. On a scale from 1 to 5, with 1 being <u>never</u> seasick and 5 being <u>extremely</u> seasick, how seasick do you usually get? Circle one of the following numbers.

Never seasick Extremely seasick

45. What type or remedy have you used for seasickness? (Medical or otherwise) (You may choose more than one response)

1 = Vomit
2 = Motion sickness pill
3 = Fresh air

4 = Nothing
5 = Other (please specify)

46. How well does your remedy work? (Leave blank if never been seasick)

1 = Very well
2 = Very well at first, but nausea returned
3 = Fairly well
4 = Fairly poorly
5 = Not at all

47. Have you reported to sick call due to seasickness?

1 = Yes
2 = Yes, but felt uncomfortable doing so
3 = No, because I did not feel comfortable doing so
4 = No, I took care of it myself

48. Does seeing other people experiencing seasickness make you feel seasick?

1 = Yes
2 = No
3 = Don't know

49. Does smelling strong odors (diesel smoke, fuel vapors, cigar or cigarette smoke, cooking odors) make you feel seasick?

1 = Definitely yes
2 = Somewhat yes
3 = Somewhat no
4 = Definitely no
5 = Don't know